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Changes in rainfall partitioning caused by the replacement of native dry forests of *Lithraea molleoides* by exotic plantations of *Pinus elliottii* in the dry Chaco mountain forests, central Argentina

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Abstract: The replacement of native dry forests by commercial (exotic) tree plantations could generate changes in rainfall partitioning, which further affects the water cycle. In this study, we determined (i) the rainfall partitioning into interception, throughfall and stemflow, (ii) the role of rainfall event size on rainfall partitioning, (iii) the pH of water channelized as throughfall and stemflow, and (iv) the runoff in *Lithraea molleoides* (a native species) and *Pinus elliottii* (an exotic species) stands in the dry Chaco mountain forests, central Argentina. On average, interception, throughfall and stemflow accounted for 19.3%, 79.5% and 1.2% of the gross rainfall in *L. molleoides* stand, and 32.6%, 66.7% and 0.7% of the gross rainfall in *P. elliottii* stand, respectively. Amounts of interception, throughfall and stemflow presented positive linear relationships with the increment of rainfall event size for both tree species (*P*<0.01 in all cases). Percentages of interception, throughfall and stemflow were all related to the increment of rainfall event size, showing different patterns. With increasing rainfall event size, interception exponentially decreased, throughfall asymptotically increased and stemflow linearly increased. Both *P. elliottii* and *L. molleoides* stands presented significant differences in the pH values of water channelized as throughfall (6.3 vs. 6.7, respectively; *P*<0.01) and stemflow (4.5 vs. 5.8, respectively; *P*<0.01). Runoff occupied only 0.3% of the gross rainfall in *P. elliottii* stand and was zero in *L. molleoides* stand. Our results showed that the native species *L. molleoides* presented 13.6% more water reaching the topsoil (i.e., net rainfall; net rainfall=gross rainfall–interception–runoff) than the exotic species *P. elliottii*. This study improves our understanding of the effects of native vegetation replacement on the local water balance in the dry forest ecosystems.

Keywords: drylands; ecohydrology; land use changes; spatial heterogeneity; water-limited environments

1   Introduction

Dry forests cover approximately 16% of the global land surface (Olson et al., 2001) and represent one of the most threatened ecosystems (Hoekstra et al., 2005). These forests influence on the rainfall pathway from the canopy to the soil surface, and also from the top soil to the groundwater zone and streamflow (Ellison et al., 2017; Sadeghi et al., 2020). Several studies highlighted that hydrological processes are sensible to land cover changes (e.g., native dry forests replacement by exotic plantations) by altering the liquid and vapor fluxes of the water balance (Fahey et al., 2001; Eberbach, 2003; Reichert et al., 2017). Exotic plantations have been largely expanded around the world, generating justified concern about their impacts on water resources, particularly in drylands (Richardson and Rejmánek, 2011; Sadeghi et al., 2016; Whitworth-Hulse et al., 2020). Therefore, addressing the ecohydrological relations between rainwater inputs and vegetation attributes becomes an important issue that may influence the water resource management and native forest sustainability in the long run.

Dry forest canopy regulates the quantity and quality (e.g., chemical properties) of water reaching the soil surface by partitioning rainfall into interception, throughfall, stemflow and runoff (Lilienfein and Wilcke, 2004; Raz-Yaseef et al., 2010; Fan et al., 2015; Magliano et al., 2016). In general terms, the relatively contributions of throughfall, interception, stemflow and runoff to the gross rainfall are >60.0%, <30.0%, <10.0% and <5.0%, respectively (Levia and Frost, 2003; Llorens and Domingo, 2007; Nouwakpo et al., 2016; Magliano et al., 2019a). Interception represents the fraction of rainwater that is retained on the canopy and then evaporated (Dunkerley 2000; Fan et al., 2014); and therefore, this flux shows a negative effect on plant water consumption (Návar and Bryan, 1990; Magliano et al., 2019b). In contrast, the remaining rainfall amount reaches the ground as throughfall and/or stemflow (Zheng et al., 2018, 2019). Throughfall is the fraction of water transfers to the ground through the canopy gaps without hitting the canopy surfaces or through dripping from the leaves and branches (Zhang et al., 2019; Whitworth-Hulse et al., 2020). Furthermore, this flux contributes to the spatial distribution of soil water, particularly in the top soil layers (Shachnovich et al., 2008; Zhang et al., 2016). Stemflow delivers rainwater to the ground around the base of shrubs and trees, and channels water to the root zone, remaining available for its absorption (Li et al., 2008; Levia and Germer, 2015; Yuan et al., 2019; Zhang et al., 2020). Meanwhile, the fraction of rainfall that reaches the soil surface, but not infiltrates, contributes to the runoff flux, which is considered a net water loss at the stand scale (Wilcox et al., 2003; Ludwig et al., 2005).

From a perspective of increasing (or at least not decreasing) net primary production of dry forest ecosystems, it is desirable that interception and runoff remain as low as possible. However, the ecohydrological impacts attributed to the replacement of high diverse native vegetation by mono-specific exotic plantations involve the increment of those two fluxes (Farley et al., 2005; Nosetto et al., 2012; Reichert et al., 2017). For instance, plantations of *Pinus nigra* and *Pinus halepensis* intercept approximately 50% of the rainfall (Llorens and Domingo, 2007; Molina and del Campo, 2012). In the case of soil surface runoff, Kothyari et al. (2004) found a positive response between this flux and rainfall event size in coniferous plantations from Central Himalaya, attributing the results to the simplified structure of the exotic vegetation. Furthermore, recent studies highlighted that the water quality of throughfall and stemflow under plantations is also modified in terms of chemical properties (Kothyari et al., 2004; Hervé-Fernandez et al., 2016). For example, Leiva and Frost (2003) reported that the pH of throughfall is lower under coniferous canopies than under deciduous or mixed conifer-deciduous canopies. It is worth mentioning that the decrease in the pH values of soils (i.e., acidification) alters the mobility of some nutrients, and therefore may affect plant growth of some species (Certini et al., 1998; Silva and Rodríguez, 2001; Lilienfein and Wilcke, 2004).

The dry mountain forests of Chaco, expanding over 1.0×10^6 km^2, are the second-largest forest extension in South America after the Amazonia (Houspanossian et al., 2016). This region is one of the few dry forests in the world that still conserves a large proportion (about 70.0%) of its native vegetation (Baldi and Jobbágy, 2012). Nonetheless, land cover change rates have sped up

dramatically in the last two decades, reaching top records in comparison to the global pattern (Hansen et al., 2013). The most common land cover change is the replacement of native forests by extensive croplands in the plain landscapes and by exotic *Pinus* spp. plantations in the mountainous areas (Gasparri and Baldi, 2013; Hoyos et al., 2013; Jobbágy et al., 2013). In particular, the ecohydrological changes caused by the implantation of exotic trees in the mountainous areas of central Argentina can involve not only variations in net primary production dynamics, but also a decrease in the water yield of permanent and ephemeral rivers affecting water provision for people that live in those areas (Dorado et al., 1997; Jobbágy et al., 2008, 2013).

In this study, (i) the rainfall partitioning into interception, throughfall and stemflow, (ii) the role of rainfall event size on rainfall partitioning, (iii) the pH of water channelized as throughfall and stemflow, and (iv) the runoff, were determined in native and exotic forest stands of *Lithraea molleoides* and *Pinus elliottii*, respectively, in the dry Chaco mountain forests (central Argentina). So far, there is no evidence about the role that rainfall partitioning has on this threatened region, where vegetation is rapidly and massively being replaced.

2 Study area and methods

2.1 Study area

This study was carried out in the dry Chaco mountain forests of Córdoba Province, central Argentina (31°50′–31°58′S, 64°57′–64°59′W; 1078–1180 m a.s.l.; Fig. 1a). The landscape matrix involves a mosaic of vegetation physiognomies, highlighting the native dry forests mainly dominated by *L. molleoides*, exotic trees, shrubs and grasses (Giorgis et al., 2017; Oyarzabal et al., 2018). The major drivers of this mosaic pattern are the fire regime, high rates of logging, overgrazing and spread of exotic plant species (Gavier and Bucher, 2004). In the last four decades, native forests and shrublands have been replaced by commercial (exotic) mono-specific tree plantations of *Pinus* spp. (Hoyos et al., 2013; Jobbágy et al., 2013). The study area is characterized by a semi-arid climate with the ratios of precipitation to reference evapotranspiration between 0.40–0.65 (Trabucco and Zomer, 2009). Specifically, in the field stands, mean annual precipitation is 576 mm and mean annual potential evapotranspiration is around 1400 mm (National Meteorological Service of Argentina; https://www.smn.gob.ar/). About 81% of rainfall events are concentrated in the spring–summer season from October to April (Magliano et al., 2015). The soils are Lithic Torriorthents (Pennington et al., 2000; Karlin et al., 2013) and slopes are determined by the topographic position in the mountains, presenting typical values of 10%–15%.

2.2 Experimental design and data collection

The experiment was conducted on two representative mature dry forest stands (60 m×60 m for each), one covered by the native species *L. molleoides* and the other covered by the exotic species *P. elliottii* (Shachnovich et al., 2008; He et al., 2014; de Queiroz et al., 2020). Both stands had the same biophysical conditions except for the woody vegetation composition and structure (Fig. 1b and c). Field measurements took place from 2 June 2015 to 3 October 2016. Leaf area index values were 1.6 and 2.4 for *L. molleoides* and *P. elliottii* stands, respectively, while mean height values were 10.4 and 20.6 m for the two stands, respectively. Both tree species are evergreen and rough-barked; specifically, *L. molleoides* has pinnate leaves and low branch inclination angles and *P. elliottii* has needle-leaves with branches horizontally orientated. We measured stemflow with collectors at 10 individual trees (n=10) and determined throughfall using three randomly located gutters with an open surface of 0.9 m^2 for each one (n=3). It is worth mentioning that large-size fixed gutters are particularly good at obtaining the amount of throughfall (the aim of our study), but they cannot capture the spatial variation of throughfall. We determined interception as the difference among gross rainfall, stemflow and throughfall according to the description of Zhang et al. (2015). Furthermore, we measured runoff by installing one rectangular plot (20 m×5 m=100 m^2) per forest stand. Each plot presented an average slope of 11%. We obtained stemflow, throughfall, interception and runoff amounts for each rainfall event, and converted each mean value to the percentage of the gross rainfall for each event.
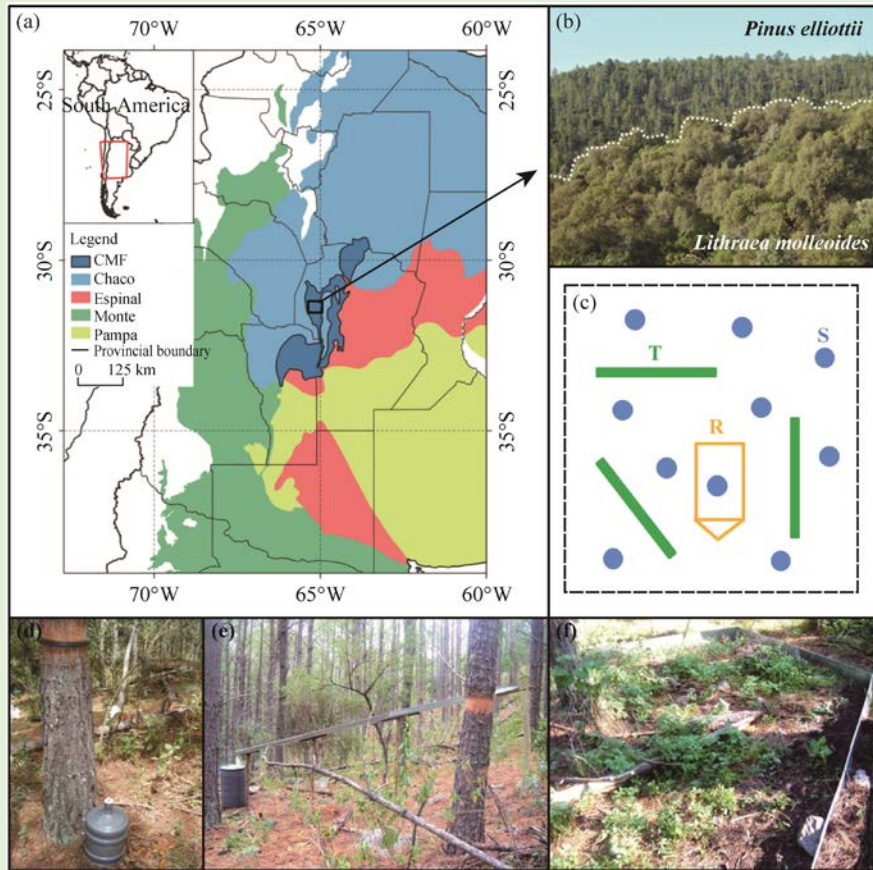
Fig. 1   Location of the study site, experimental design and field measurements. (a), location of the study site in the dry Chaco mountain forests (CMF) of Córdoba Province, central Argentina; (b), photo taken at field that shows the exotic tree plantations of *Pinus elliottii* (behind) and the native dry forests of *Lithraea molleoides* (in the front; the dotted line separates the two vegetation covers); (c), schematic representation of the experimental design of one forest stand with the corresponding field measurements: stemflow (S) in trees (blue circles; *n*=10), gutters to measure throughfall (T) (green lines; *n*=3) and runoff (R) plot (orange shape; *n*=1); (d), measurement of stemflow; (e), measurement of throughfall; (f), measurement of runoff.

We calculated each rainfall event size by averaging three manual rain gauges situated in open canopy areas, i.e., three gauges in *L. molleoides* stand and three in *P. elliottii* stand. A rainfall event was defined as a rainfall period from preceding and succeeding rainfall being separated by at least 24 h without rainfall. During the study period, we measured 25 and 23 individual rainfall events in *L. molleoides* and *P. elliottii* stands, respectively. It should be noted that not all the rainfall events were measured simultaneously at both stands, that is to say, some rainfall events were measured only in one stand and some in another one. We determined the pH values of stemflow and throughfall samples at five rainfall events according to the method of Bates (1964).

Stemflow was collected with a plastic collar wound round the tree trunk at 1.3 m height, and drained through a rubber pipe to a graduated tank of 20 L, which was emptied after each stemflow measurement (Fig. 1d). The height and basal area of each tree were measured with a graduated telescopic stick and a specially calibrated tape, respectively. The projected canopy area was determined as a circumference by measuring the canopy diameter. At each rainfall event, stemflow was determined for each individual tree and then averaged (*n*=10 trees) using the following equation:

$$S = SV/PCA, \tag{1}$$

where S is the stemflow depth (cm); SV is the stemflow volume (cm^3); and PCA is the projected canopy area (cm^2).

Throughfall gutters were installed under the canopy and placed 1.0 m above ground (Fig. 1e). Each gutter was connected to a graduated tank collector of 200 L, which was emptied after each throughfall measurement. Throughfall at each rainfall event was determined using Equation 2:

$$T = \sum TV/n \times GRA, \tag{2}$$

where T is the throughfall depth (cm); TV is throughfall volume (cm^3) for each gutter; n is the number of gutters installed under the canopy; and GRA is the gross rainfall area of each gutter (cm^2).

Interception at each rainfall event was calculated by Equation 3:

$$I = GR - S - T, \tag{3}$$

where I is the interception (cm); GR is the gross rainfall in an open canopy area (cm); S is the stemflow depth (cm); and T is the throughfall depth (cm).

Runoff plots were constructed with zinc metal sheets that were buried 10 cm from the soil surface and protruded 10 cm from it (Fig. 1f). Each plot was connected to a graduated tank collector of 200 L (Whitworth-Hulse, 2018). The tank collectors were emptied after each runoff measurement. Runoff at each rainfall event was determined using Equation 4:

$$R = GRV/PA, \tag{4}$$

where R is the runoff depth (cm); GRV is the gross rainfall volume collected in the plot (cm^3); and PA is the area of the plot (cm^2).

2.3 Data analysis

Descriptive statistics were computed for rainfall partitioning fluxes (e.g., the amount and percentage values of interception, throughfall and stemflow), and pH analysis (in the cases of throughfall and stemflow). *T*-tests were performed to determine statistical differences between both tree species assuming a significance level of 0.05. Linear and nonlinear regression models were performed to determine the relations of rainfall event size with interception, throughfall and stemflow (amount and percentage values). Akaike's information criterion was used to obtain the fitted equation of each relationship performed (Akaike, 1974).

3 Results

The replacement of native dry forests of *L. molleoides* by exotic tree plantations of *P. elliottii* generated changes in the amount and quality of rainfall that reached the ground. More specifically, rainfall partitioning into interception, throughfall and stemflow presented significant differences between *L. molleoides* and *P. elliottii* stands (Fig. 2). Interception was higher in *P. elliottii* stand than in *L. molleoides* stand (32.6% vs. 19.3%, respectively; *P*=0.03), while throughfall showed the opposite pattern (79.5% vs. 66.7% in *L. molleoides* and *P. elliottii* stands, respectively; *P*=0.03). Although stemflow was 58.0% higher in *L. molleoides* stand than in *P. Elliottii* stand (*P*=0.05), it represented a very small flux in both cases (1.2% vs. 0.7% in *L. molleoides* and *P. elliottii* stands, respectively). In *L. molleoides* stand, interception was the most variable flux, followed by stemflow (coefficient of variations (CVs) of 90.7% and 74.0%, respectively); while in *P. elliottii* stand, stemflow was the most variable flux, followed by interception (CVs of 111.4% and 77.7%, respectively).

Amounts and percentages of interception, throughfall and stemflow as a function of rainfall event size in *L. molleoides* and *P. elliottii* stands are shown in Figure 3. Interception, throughfall and stemflow amounts presented positive linear relations with rainfall event size in *L. molleoides* and *P. elliottii* stands (*P*<0.01 in all cases; Fig. 3a, c and e). The significant response of interception to rainfall event size was higher in *P. elliottii* stand than in *L. molleoides* stand (slopes of 0.22 and 0.13, respectively; Fig. 3a). Throughfall and stemflow presented the opposite pattern, and their response to rainfall event size was higher in *L. molleoides* stand than in *P. elliottii* stand. The slopes of throughfall variation were 0.92 and 0.82 in *L. molleoides* and *P. elliottii* stands, respectively (Fig. 3c), while the slopes of stemflow variation were 0.03 and 0.01 in *L. molleoides*
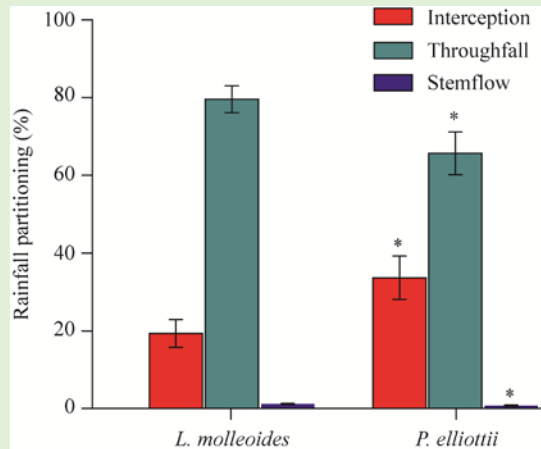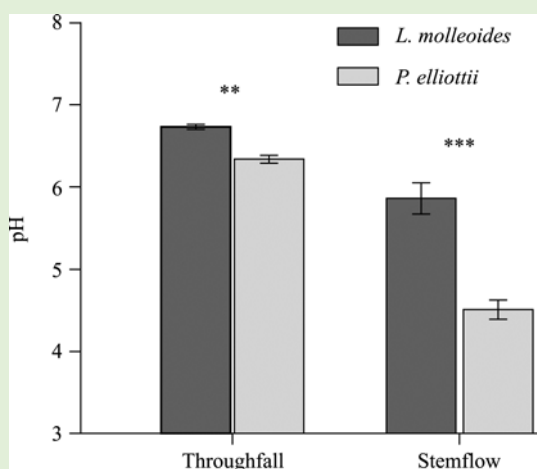
Fig. 2 Rainfall partitioning into interception, throughfall and stemflow in *L. molleoides* and *P. elliottii* stands. Vertical bar represents standard error. * means significant differences between the two species at *P*<0.05 level.
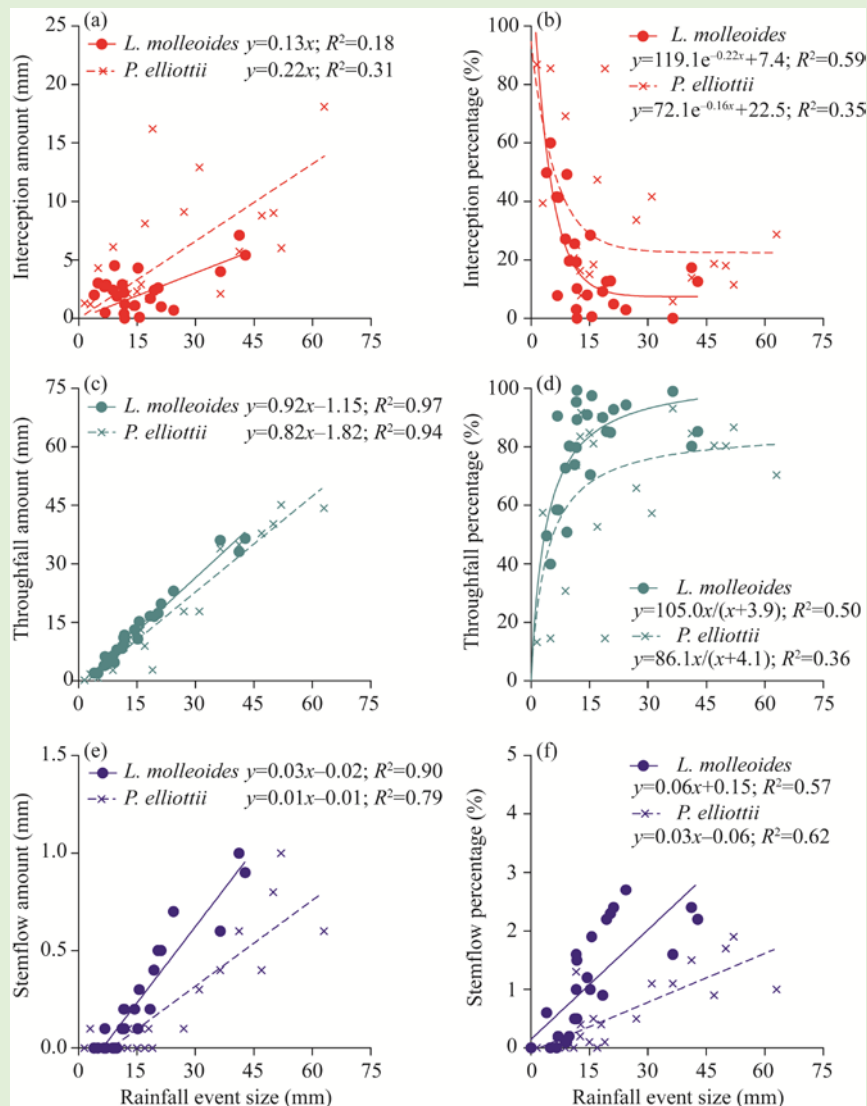
Fig. 3 Amounts (a, c, e) and percentages (b, d, f) of interception, throughfall and stemflow as a function of rainfall event size in *L. molleoides* and *P. elliottii* stands

and *P. elliottii* stands, respectively (Fig. 3e). The rainfall threshold values for stemflow generation were 6.1 and 8.4 mm in *L. molleoides* and *P. elliottii* stands, respectively. Interception, throughfall and stemflow percentages were also associated with rainfall event size, displaying different patterns (Fig. 3b, d and f). Interception decreased exponentially with increasing rainfall event size for both tree species, with the lowest value in *L. molleoides* stand (Fig. 3b). Throughfall increased asymptotically with increasing rainfall event size for both tree species, with the highest value in *L. molleoides* stand (Fig. 3d). Stemflow linearly increased with increasing rainfall event size, presenting a higher slope in *L. molleoides* stand (Fig. 3f).

The pH of water channelized as throughfall and stemflow was lower (more acid) in *P. elliottii* stand than in *L. molleoides* stand (*P*<0.01; Fig. 4). In the case of throughfall, *L. molleoides* stand presented an average pH of 6.7, while *P. elliottii* stand exhibited an average pH of 6.3. Regarding the stemflow, the pH values were 5.8 and 4.5 in *L. molleoides* and *P. elliottii* stands, respectively. So, the pH values of water channelized as stemflow were 14.0% and 29.0% lower than those of water channelized as throughfall in *L. molleoides* and *P. elliottii* stands, respectively. In other words, rainfall became more acid when it was funnelled by the stem than when it crossed the branches and leaves via throughfall, especially in *P. elliottii* stand.

Fig. 4   The pH values of water channelized as throughfall and stemflow in *L. molleoides* and *P. elliottii* stands. Vertical bar represents standard error (*n*=5 rainfall events). ** and *** mean significant differences between the two tree stands at *P*<0.01 and *P*<0.0001 levels, respectively.

Runoff occupied 0.3% of the gross rainfall in *P. elliottii* stand and was zero in *L. molleoides* stand. These values were very low even considering the occurrence of single rainfall event larger than 30 mm during the study period. So, it can be assumed that the amount of water that reaches the topsoil was mainly affected by canopy interception losses. As a result of the sum of all rainfall events measured in the experiment, the total net rainfall (net rainfall=gross rainfall–interception–runoff) was 80.7% and 67.1% in *L. molleoides* and *P. elliottii* stands, respectively.

4   Discussion

Rainfall partitioning into interception, throughfall, stemflow and runoff plays a key role in dry forests, regulating the amount and quality of water inputs (Carlyle-Moses, 2004; Loik et al., 2004; Zhang et al., 2015). Evaluating the quantitative importance of canopy interception losses is a crucial issue in terms of water availability in drylands where soil moisture is a limiting factor. Our results showed that the replacement of native dry forests of *L. molleoides* by exotic tree plantations of *P. elliottii* generated a significant increment in the interception losses and also a reduction of throughfall and stemflow fluxes (Figs. 2 and 3), diminishing the rainwater that reaches the topsoil. Moreover, the pH values of water channelized as both throughfall and

stemflow were lower in *P. elliottii* stand than in *L. molleoides* stand (Fig. 4). It is important to mention that the higher canopy interception losses of *P. elliottii* stand can be assumed as less water available for transpiration, which may negatively impact on the net primary productivity.

From an ecohydrological perspective, the replacement of native vegetation by mono-specific tree plantations can introduce changes in evapotranspiration (directly related to net primary productivity) and water yield of the permanent rivers. Our results showed that *P. elliottii* plantations presented 13.6% less water reaching the topsoil than *L. molleoides* plantations, suggesting that net primary productivity should be lower. However, we further evaluated the annual temporal dynamics of Normalized Difference Vegetation Index (NDVI) as a surrogate of evapotranspiration or net primary productivity (Fensholt et al., 2004; Nosetto et al., 2012) and found an opposite pattern. The result shown in Figure 5 indicated that on average of the whole year, NDVI of *P. elliottii* stand was 11.0% higher than that of *L. molleoides* stand ($P<0.01$). This contradiction (lower net rainfall but higher NDVI of *P. elliottii* stand) can be explained by the reduction of water yield of the main permanent river of the watershed. A previous research measured the river flow before (upland) and after (lowland) the *P. elliottii* plantations, and found a reduction of 56.0% in water yield (Cortés, 2018). These results are consistent with other studies conducted in another watershed of the same area, as well as, in similar environments worldwide (Farley et al., 2005; Llorens and Domingo, 2007; Jobbágy et al., 2008, 2013). Jobbágy et al. (2013), for example, suggested a decreasing of 48.0% of water yield caused by the replacement of native grasslands by exotic *P. elliottii* plantations in the eastern slope of the Córdoba Mountains, Argentina.
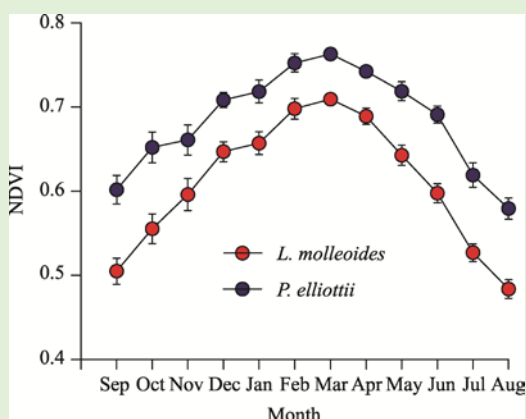
Fig. 5 Intra-annual temporal dynamics of Normalized Difference Vegetation Index (NDVI) in *L. molleoides* and *P. elliottii* stands. NDVI data were derived from MODIS imagery (MOD13Q1 V6 product) and downloaded from the Oak Ridge National Laboratory Distributed Active Archive Center (https://modis.ornl.gov/globalsubset/). Data were corresponded to two stand sites (each area of 250 m×250 m) where the field measurements were carried out: *L. molleoides* site (31°54′08″S, 64°58′10″W) and *P. elliottii* site (31°58′49″S, 64°59′19″W). Each circular marker represents the mean value (*n*=10 a) and vertical bar represents standard error.

Previous studies focused on *Pinus* spp. plantations showed that interception, throughfall and stemflow accounted for, on average, 26.7%, 70.6% and 2.8% of the gross rainfall, respectively (Table 1). Our results showed that interception losses were higher while both throughfall and stemflow were lower than those mean values. However, the values of this study were very similar with those of van Stan et al. (2017), who also focused their study on *P. elliottii* plantations (Table 1). In addition, the pH values of plantations in previous studies also presented similar magnitudes with the results of our study (Certini et al., 1998; Silva and Rodríguez, 2001; Lilienfein and Wilcke, 2004). In this sense, soil acidification has been reported in coniferous forests as a result of rainfall pathway from the canopy to the ground via throughfall and stemflow (Qualls, 2020). Acidification process may increase the aluminum concentrations in the soil solution, and therefore might negatively affect the mobility of essential nutrients for plant growth (Wright, 1989; Kochian, 1995). Regarding rainfall redistribution in *L. molleoides* forests, Whitworth-Hulse

(2018) reported similar values of interception, throughfall, stemflow and runoff in a dry forest close to our study area, but unfortunately, there are no data focusing on rainwater chemical properties to compare with our findings.

Table 1 List of studies that determined the percentages of interception, throughfall and stemflow in *Pinus* spp. plantations

Reference	*Pinus* species	Percentage (%)		
		Interception	Throughfall	Stemflow
Lilienfein and Wilcke (2004)	*P. caribaea*	24.5	80.0	0.5
McKee and Carlyle-Moses (2017)	*P. contorta*	-	-	1.8
Carlyle-Moses et al. (2014)	*P. contorta*	40.6	59.4	0.0
Anderson and Pyatt (1986)	*P. contorta*	29.0	61.0	10.0
Sadeghi et al. (2016)	*P. eldarica*	45.0	51.0	4.0
van Stan et al. (2017)	*P. elliottii*	35.5	64.5	0.1
Molina and del Campo (2012)	*P. halepensis*	-	55.9	1.5
Shachnovich et al. (2008)	*P. halepensis*	-	-	1.6
Ji and Cai (2015)	*P. koraiensis*	21.5	76.8	1.8
Chai et al. (2013)	*P. koraiensis*	25.6	72.6	1.7
Domingo et al. (1994)	*P. nigra*	-	84.3	12.3
Certini et al. (1998)	*P. nigra*	-	70.0	3.7
Miller and Williams (1974)	*P. nigra*	-	66.0	3.0
Valente et al. (1997)	*P. pinaster*	17.1	82.6	0.3
Domingo et al. (1994)	*P. pinaster*	–	85.9	1.5
Silva and Rodriguez (2001)	*P. pinaster*	17.1	82.6	0.3
Mazza et al. (2011)	*P. pinea*	31.5	68.5	0.2
Licata et al. (2011)	*P. ponderosa*	19.5	74.0	3.0
Navar (2011)	*P. pseudostrobus*	-	-	0.4
Silva and Rodriguez (2001)	*P. pseudostrobus*	19.2	-	0.6
Fahey et al. (2001)	*P. radiata*	20.0	75.0	5.0
Aydın et al. (2018)	*P. sylvestris*	20.2	73.9	5.9
Cayuela et al. (2018)	*P. sylvestris*	-	-	1.0
Soulsby et al. (2017)	*P. sylvestris*	46.0	55.0	1.3
Liu et al. (2016)	*P. sylvestris*	29.5	69.3	1.3
Cape et al. (1991)	*P. sylvestris*	20.0	64.5	10.5
Abrahamson et al. (1998)	*P. taeda*	9.5	84.0	3.4
This study	*P. elliottii*	32.6	66.7	0.7
Mean		26.5	70.6	2.8
CV		37.7	14.3	118.3

Note: In the cases where the authors presented a range, we averaged the minimum and maximum values instead of a single value. -, no data. CV, coefficient of variation.

5   Conclusions

The replacement of native dry forests by commercial (exotic) tree plantations generated strong changes in rainfall partitioning affecting the amount and quality of water inputs. We found that the exotic tree species *P. elliottii* showed more interception losses and less throughfall and stemflow than the native tree species *L. molleoides*. Furthermore, *L. molleoides* exhibited a higher response of throughfall and stemflow to the increment of rainfall event size than *P. elliottii*. The pH of water channelized as throughfall and stemflow was lower (more acid) in *P. elliottii* stand than in *L. molleoides* stand. Moreover, runoff was very low in *P. elliottii* stand (0.3% of the gross rainfall) and was zero in *L. molleoides* stand. These results showed that native *L. molleoides* stand presented 13.6% more water reaching the topsoil (i.e., net rainfall; net rainfall=gross

rainfall–interception–runoff) than exotic *P. elliottii* stand. This study, based on two years of field measurements for native and exotic tree species, provides a preliminary insight of how vegetation regulates the rainfall partitioning in water-limited environments in the dry Chaco mountain forests.

Acknowledgements

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